WATER RESOURCES RESEARCH GRANT PROPOSAL

TITLE: Genetic Algorithms for the Control of Sedimentation in River-Reservoir Networks

FOCUS CATEGORIES: SED, M&P, MET

KEYWORDS: Sedimentation, Optimization, Water Resources Planning, Decision Models, Discrete-Time Optimal Control, Reservoir Management, Systems Engineering, Alluvial Rivers, Genetic Algorithms, Sediment Transport Simulation

PROJECT DURATION: May 16, 1999 to May 15, 2001

FEDERAL FUNDS REQUESTED: $30,804.

NON-FEDERAL FUNDS REQUESTED: $61,610.

PRINCIPAL INVESTIGATOR: John W. Nicklow; Southern Illinois University at Carbondale

CONGRESSIONAL DISTRICT: 12th District, Illinois

PROBLEM STATEMENT

Alluvial rivers and reservoirs frequently adjust their geometry and conveyance patterns through natural processes of sediment transport. If left uncontrolled, however, excessive scour of a streambed will induce major shifts in boundary geometry and can threaten stability of in-stream structures, such as bridges or underground utilities. Likewise, continued deposition of bed sediment will cause reduced storage capacities in stream channels and in conservation and flood control reservoirs. This decline in storage eventually eliminates the intended capacity for flow regulation and water supply, and reduces the hydroelectric power generation, navigation and recreation benefits that are dependent on reservoir storage. Concentrated accumulation of sediment can also reduce water quality when the transported materials have previously been exposed to and become attached to contaminants, such as those found in some agricultural lands. Although difficult to quantify on a global basis, Mahmood (1987) estimates that reservoirs in particular are losing storage capacity as rapidly as one percent per year and that the annual cost of sediment accumulation has approached $6 billion. Problems associated with excess sedimentation have been evident on a regional basis as well. Consider, for example, Lake Shelbyville and Carlyle Lake on the Kaskaskia River in central Illinois, both of which are operated by the U.S. Army Corps of Engineers, St. Louis District. Preliminary information from the Hydrologic Engineering Division of the St. Louis District indicates that of Illinois reservoirs, Carlyle Lake has been the most effected by sediment accumulation. The Illinois Environmental Protection Agency has labeled water quality in the lake as "fair" and identified runoff and deposition of sediment from agricultural lands and eroded shorelines as causes of pollution (IEPA 1998). Within Carlyle Lake, deposition is occurring at an estimated rate of three times that which was initially expected and will dramatically shorten the useful life of the reservoir (Dyhouse 1998). Subsequently, the geometry and sediment balance of the multi-reservoir river system as a whole will be affected.

Sustainability of rivers and reservoirs is a difficult and costly issue to address after problems have occurred. As an example, it would cost $83 billion to restore Lake Powell on the Colorado River to its original capacity once fully sedimented, assuming a disposal facility would accept the 43 billion cubic yards of dredged material (Morris and Fan 1998). Despite the adverse effects caused by excess sedimentation, there has been minimal effort applied to the development of preventive, control methodologies that limit sedimentation in rivers and reservoirs. In contrast, considerable effort has been focused on developing simulation models that predict sediment movement in alluvial systems. Although these simulators are useful in assessing "what-if" questions concerning bed sediment response for a hydrologic event, they cannot directly solve complex control problems that require decisions to be made. Since channel discharges, or reservoir releases, constitute the most important controllable factor that affects morphology of a river-reservoir network, these decisions involve determination of an optimal reservoir release policy that minimizes the adverse effects of sedimentation for forecasted storms. A general application methodology is needed by reservoir management and planning authorities to efficiently identify short- or long-term optimal reservoir operations that control sedimentation. The methodology should account for uncertainties on parameters such as sediment grain size and transport capacity and contributing runoff to reservoirs. Subsequently, the methodology must attempt to overcome historical gaps between theoretical developments in optimization and practical reservoir management. This proposal focuses on the development of such a methodology that will provide a cost-effective means for sustaining the benefits that regional water resources are capable of providing.

STATEMENT OF RESEARCH BENEFITS

This research is unique in its use of natural optimization methods as part of a decision-making mechanism for sedimentation control and in its advancement of optimization models to solve realistic engineering problems. Specifically, benefits of the research have the following aspects:

1. No methodology presently exists that can efficiently identify multiple-reservoir releases that minimize sedimentation while considering the uncertain nature of sediment and hydrologic variables. The results of this research will provide such a methodology that can be used by reservoir management authorities and analysts to control the adverse effects of sedimentation.

2. No previous attempts have been made to evaluate multi-reservoir releases for sedimentation control under conditions of uncertainty. This is especially unique since the

problem posed is a realistic and important aspect of sustainable, productive river-reservoir systems.

3. This will be the first attempt to apply genetic algorithms for solution to the sedimentation problem. Results of this research will reveal important information concerning the general applicability and effectiveness of these natural optimization techniques. There are many other realistic water resources management problems that may benefit and could be solved once the overall solution methodology has been developed and tested.

4. Many previously developed reservoir operation models require simplification of problem size or dynamics and have not been readily adopted by reservoir management authorities due to the complex nature of the model. The proposed research emphasizes use of an established hydraulic and sediment transport simulator into the overall solution approach. As a result, the limitations are only those inherent to the simulation model, and additional problem simplifications are not needed. Furthermore, by limiting optimization data required, those who are familiar with the simulator can use this decision-making tool with minimal additional technical knowledge.

5. The project will benefit the career advancement of a new faculty member and his research efforts, and support a Southern Illinois University student in completion of a graduate degree.

RESEARCH OBJECTIVES

Rivers and reservoirs cannot be viewed as replaceable resources given the current global environment. As a result, focus should be directed toward adequate decision-making models that promote resource sustainability. The objective of this research is to develop a methodology and computational model for efficiently determining reservoir releases that minimize sedimentation in a multiple-reservoir river network. In this context, the term sedimentation could define total cumulative scour and deposition occurring in an alluvial network, scour and deposition only at specified critical locations in the network, or cost of alleviating the problems caused by scour and deposition. The resulting model will serve as a decision-making mechanism to assist water management authorities in controlling sedimentation and, thus, sustaining river-reservoir systems and their associated benefits.

The sedimentation control problem represents a large-scale, nonlinear programming problem for which there are no explicit solution schemes. The problem can, however, be solved using a discrete-time optimal control approach that is based on a computational interface between simulation techniques and nonlinear optimization methods. This particular optimal control model will rely upon a sediment transport simulation model to solve governing hydraulic and sediment transport constraints and a natural optimization procedure called genetic algorithms to solve the master optimization problem. Uncertainties on sediment characteristics and hydrologic inputs will be accommodated using a chance-constrained formulation of the problem. The model will identify short- or long-term optimal reservoir operations that control sedimentation and will be capable of considering any configuration of a dendritic, single- or multiple-reservoir system. Emphasis will be placed on creating a computationally efficient model that locates a globally optimal reservoir operating policy with a high degree of reliability. Additionally, the optimal control model will incorporate a familiar sediment transport simulator that engineers and reservoir management authorities have previously accepted and will limit additional data requirements beyond that of the simulator. These steps will be taken in efforts to close the apparent gap between theoretical developments in optimization research and practical water resources management.